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BIOLOGICAL AMENDMENTS TO IMPROVE FOREST SOIL

THE MICROENVIRONMENT OF THE RHIZOSPHERE is the primary passageway for most interactions between plants and soil. As a root extends through the soil it does not encounter a simple dead organic-inorganic system, but a system teeming with life. Serving as the hub, the root is surrounded by a specialized arrangement of bacteria, fungi, nematodes, protozoa, and sometimes algae. Exudates from roots may serve as nourishment or sometimes as inhibitors in the physiological activities of the microorganisms. Any particular living root, consequently, is surrounded by a variety of living organisms in arrangement that is quite different from similar root-free soil.

Forest Soils

Forest soils contain an exceedingly complex mixture of microorganisms. Examination of the influences of rhizosphere components on each other is tedious, consequently most such research thus far has been analytical. Microorganisms, mainly fungi, that cause tree diseases, have been studied more intensively than nonpathogenic forms. Economic implications would naturally indicate that control of such diseases be a major area of research. Effects of beneficial microorganisms in forests have not been studied as extensively as in agricultural crops. Inoculation of legumes with selected strains of nitrogen-fixing bacteria is the best known example of a tailor-made biological system that greatly enhanced the culture of a specific crop. To some extent inoculation of trees with mycorrhizal fungi has been used in soils devoid of appropriate fungi. However, the practical use of biological amendments—introduction of living organisms into forest soils to make them more productive—is very limited.

Careful analysis of the interactions between tree roots and rhizosphere organisms should yield considerably greater returns than in the past. Biological systems could then be synthesized to help regulate development of disease organisms and effectively promote survival and vigorous tree growth. Without attempting a broad review of the subject some specific achievements in use of biological amendments, primarily microorganisms, and possibilities for lines of future research, will be discussed.

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Symbiotic Associations

Roots of woody species of certain legumes are nodulated as a result of invasions by symbiotic species of bacteria. The bacteria live in the nodules and fix atmospheric nitrogen just as they do in horticultural species of legumes. The effect is an increase in nitrogen available to the host plant, to other microorganisms in the soil, and to associated higher plants. The fertility of the soil often is increased by the presence of species that possess a nitrogen-fixing apparatus.

Certain nonleguminous species also are nodulated and are nitrogen-fixers. The associated organisms are actinomycetes rather than bacteria. *Casuarina* in the tropics has very distinctive branched nodules that superficially resemble ectomycorrhizae. In North America small shrubby species of *Ceanothus, Myrica, Shepherdia,* and *Eleagnus* are often associated with forests or potential areas for forestation. *Alnus* is widely distributed in the northern hemisphere as a nodule-bearing shrub or tree. In each of these species penetration of the roots by actinomycetes induce nodulation. The biological potential of these associations in forest trees could have extensive significance.

A recent publication on alder in the Pacific Northwest (*4*) contains reports by several authors on research that has been done on this species. The potential for use of alder as a beneficial associate of Douglas-fir is emphasized.

Among others, investigations were made on the rhizosphere microfloras of mycorrhizal and nonmycorrhizal suberized roots of Douglas-fir and red alder. It was reported that rhizosphere microorganisms were influenced qualitatively and quantitatively by the mycorrhizal fungus present. Metabolic secretions by the mycorrhizae may discourage attack by pathogenic organisms and may cause changes in microbial populations dependent upon the mycorrhizal organism in the associations. It was also reported that certain strains of

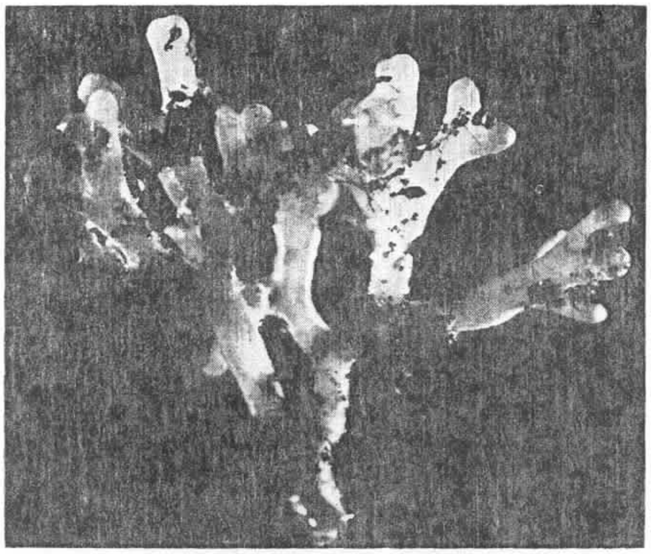

Fig. 1—Ectomycorrhizae of pine.

bacteria were active in nitrification in the F layer beneath alder despite low pH. Since bacterial development is favored in soils with high pH values it was suggested that certain strains of bacteria had adapted to local soil conditions. In addition, there exists an abundance of *Streptomyces* in the mixed stands since the actinomycete is associated with alder nodules. Production of antibiotics by these organisms could potentially reduce attacks on roots by pathogens. The beneficial effects of alder on associated conifers might be as important in forestry as legumes are in agriculture. Management of alder and other phanerogams with N-fixing nodules may be desirable in selected situations.

Colonization in Coal Wastes

In a special environmental situation Schramm (*3*) carefully studied ecological factors that permit colonization, particularly by trees, of anthracite coal wastes in Pennsylvania. The substrate is chemically devoid of nitrogen readily available for plant growth. It has been extremely difficult for vegetation to become established on the wastes. Schramm's experiments resulted in successful plantings of pines, poplars, and a few oaks. All develop ectomycorrhizae. The shrubby species that were either successfully introduced or that naturally colonized the wastes were *Robinia hispida*, *Comptonia perigrina*, and *Alnus glutinosa*. *Robinia* was equipped with bacterial and the other two with actinomycetous, nitrogen-fixing root nodules. In the case of the ectomycorrhizal trees Schramm suggested that nitrogen was supplied from the atmosphere via precipitation, since the fungi are incapable of nitrogen-fixation. The very extensive fungal hyphae of the mycorrhizae efficiently absorbed and translocated nitrogen into the root tissues. Species of plants that grew in the areas adjacent to the wastes—maples, gums, etc.—that are normally associated with endomycorrhizal fungi, could not successfully colonize the anthracite wastes. Schramm's studies are excellent examples of a careful analysis of the biology of a habitat. From his data one could go a long way toward combining appropriate biological components with appropriate management that would guarantee success in turning black mountains green again.

Mycorrhizal Inoculations

Many observations have been recorded demonstrating that mycorrhizal fungi promote growth of certain tree species in soils devoid of fungi that form ectomycorrhizae. Increased efficiency in absorption of nutrients by the branched root and associated mycorrhizal fungi (Fig. 1) is a principal factor in the stimulus. Dramatic results have been witnessed through introduction of mycorrhizal fungi in Australia, parts of Africa, the Russian Steppes, the Caribbean Islands, and in our own midwestern prairies, among others. The fungi usually were introduced into nursery beds as a mixture of organisms from forests or plantations.

One of the best documented examples of introduction of mycorrhizal inoculum recently occurred in Puerto Rico. For about 20 years seeds were imported in attempts to establish pine on the island. The seedlings grew in nursery beds to a few inches in height, displayed symptoms of extreme phosphorus deficiency, stagnated, and died. In 1955, a researcher in the Forest Service introduced soil inoculum from a stand of pines growing in the Southeastern United States to an experimental plot of slash pine seedlings in the Puerto Rican mountains. Certain trees were inoculated; others were left uninoculated. Within three years the effects were dramatic. Uninoculated plants were not more than 12 inches tall and had a small tuft of needles at their tips (Fig. 2). In contrast, inoculated plants reaches heights up to 8 feet, were thrifty and fully needled (Fig. 3). Thereafter all seedlings planted on the island were inoculated in a planned program. The Honduras strain of Caribbean pine now grows so successfully that it is not uncommon for the tree to grow ten feet in one year.

Puerto Rico provided us with a unique opportunity to study comparative effects of inoculation with indi-

Fig. 2—Nonmycorrhizal 5-year old slash pine in Puerto Rico.

Fig. 3—Five-year-old slash pine in Puerto Rico inoculated with mycorrhizal fungi three years previously.

vidual species of mycorrhizal fungi. Vozzo (*5*) used pure cultures of mycorrhizal fungi as inoculum on Caribbean pine and recorded marked growth stimulation in seedlings that developed mycorrhizae. Applications of commercial fertilizer did not offset the stunting in nonmycorrhizal seedlings.

Survival and growth of certain trees may be attributed in part to protection of roots from pathogens by ectomycorrhizae. The mechanical barrier of the dense hyphal covering of absorbing roots and in some cases secretions of antibiotics by the fungi apparently are deterrents to certain root pathogens under certain conditions (*1*). The extent to which ectomycorrhizal fungi are involved in preventing root diseases in forests is unknown, but could be significant.

Nonsymbiotic Nitrogen Fixation in Forests

Several groups of free-living microorganisms in forest soils are able to fix atmospheric nitrogen into their cells. Often these organisms live in the rhizosphere and consequently directly offset the nutritional balance of higher plants. The bacteria, *Azotobacter* and *Clostridium*, are probably the best known for their ability to fix atmospheric nitrogen or to transform ammoniacal and nitrate nitrogen to forms that can be conserved and utilized by higher plants. Certain blue-green algae fix nitrogen and their effects on availability of the element to forest trees is virtually unknown. Recently, C. B Davey (personal communication) reported that he observed unicellullar algae within tree root cells. How they got there was not known but his observation serves to focus attention to the presence and activities of algae in forest soils.

In Australia Richards (*2*) has worked with nitrogen accretion in coniferous forests. He postulated that nitrogen fixation by free-living organisms is a major factor in nitrogen nutrition in certain forests.

Future Potential

Many other important yet only slightly studied relationships in forest soils no doubt will be investigated thoroughly as interest increases and techniques become more sophisticated. We have no clear concept regarding the relationship of fungus-feeding nematodes and other animals on plant pathogenic fungi. The extent that nematode-trapping fungi might reduce the attacks on root tips by plant-pathogenic nematodes arouses curiosities. Do roots or ecto- and endomycorrhizae through secretions and other metabolic activities encourage certain microorganisms to build up and in turn provide protection to the root from pathogens on many tree species as on alder? Can the rhizosphere microfloras be tailored to increase efficiencies in cation exchanges and nutrient uptake? To what extent do microorganisms contribute growth substances such as cytokinins that affect root metabolism? Can specific organisms be encouraged to develop and produce growth substances that in turn produce desired metabolic responses in trees? These and many other questions eventually will be answered.

Conclusion

Here we can cite only a few instances where biological amendments are specifically used to improve forestry practices. I visualize slow but steady changes in general practices in forestry by incorporating techniques for manipulating and encouraging desirable microbiological systems as the techniques are available. We detect the great potential of experimentally managing alder along with conifers to determine their nutritional value and their potential as root disease deterrents. We can see how it would be possible to turn anthracite coal banks from black to green by carefully managing the planting of trees or shrubs that are associated with appropriate nitrogen-fixing organisms or ectomycorrhizal fungi. The economic impact of growing pines as a result of inoculations with ectomycorrhizal fungi has been felt in many countries. Progress in incorporating biological amendments in the practice of growing trees is possible only by careful analyses to fit the particular need. The potential is phenomenal, but progress probably will be slow.

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